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Final Report

RESEARCH RECOMMENDATIONS TO ACHIEVE ENERGY SAVINGS FOR ELECTRONIC EQUIPMENT OPERATING IN LOW POWER MODES

A Summary of Previous Project Work and Identification of Future Opportunities

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Executive Summary

An increasing amount of electricity is used by equipment while they are not fully "on" and not fully "off." We call these low power modes "lopomos" (for LOw POwer MOdes). "Standby" and "sleep" are the most familiar lopomos but some new products already have many lopomos. Office equipment and consumer electronics were the earliest products to have lopomos but lopomos are now becoming common in household appliances, safety equipment, and miscellaneous products.

Lopomo energy use is responsible for about 10% of total electricity use in California homes, or about 70 W per home. This corresponds to 900 MW of connected load. It is likely to continue growing rapidly as products with high lopomo energy use penetrate the market. For example, the TV digital converter box—which can draw as much as 20 W when not in use—is likely to appear in every California home in the next five years. New homes are required to install hard-wired smoke detectors and safety outlets, both of which draw small amounts of power all the time. Other sectors, such as commercial buildings and industry, also have lopomo energy use, perhaps totaling more in aggregate than that in households but no comprehensive measurements have been made.

Concern for lopomo energy use is growing worldwide and programs like ENERGY STAR encourage reductions in lopomo energy use. Nevertheless, little research has been undertaken to estimate potential savings or promising energy-saving technologies.

A workshop was held August 26, 2002 to discuss the current state of knowledge related to lopomo energy use and suggest research areas for California and other research sponsors to pursue in reducing lopomo energy use. The Workshop participants and authors of this report recommend the following research areas:

1. Understand how much energy is *actually consumed* in the low power modes.
2. Develop energy *test procedures* for low power modes and protocols to measure their contribution to whole-building electricity use.
3. Understand *human behavior* and preferences as they relate to low power modes.
4. Investigate *feasible technologies* offering energy savings opportunities and their economic costs and savings.
5. Engage in *long-term research* to increase the efficiency of low power modes.
6. Engage in *short-term research* to address anticipated critical problems related to low power modes.

Detailed research areas were also identified, including improvements to power supplies, low-power circuitry, and clearer user interfaces for the devices. Potential savings in some cases are as large as 90%.

Some of these projects—such as development of energy test procedures—need to begin immediately. Other aspects—such as investigations of new technologies—may be longer term.

Introduction

An increasing amount of electricity is used by equipment while they are not fully "on" and not fully "off." This category of electricity use will soon have a large impact on energy demand because millions of devices already have this feature and billions more will have it in the future. The California Energy Commission's Public Interest Energy Research (PIER) Program established a project to assist in the development of an agenda for an R&D initiative on reducing this emerging use of electricity. The results of that effort are summarized in this report.

This project began with a survey of the literature, reviewing measurements completed, programs conducted, and research completed. Next, a workshop was convened on August 26, 2002 in Berkeley, California to discuss the results of the literature review and make recommendations for research. This Report summarizes the literature review and recommends areas for further research. The detailed documents—those prepared as background for the workshop and the summary of the discussions in the Workshop—are available at the Workshop website.[1]

The original intent of this project was to focus on "standby power"; however, it soon became clear that a broader perspective was needed, both for research and policy. As a result, this project addresses all "low power modes."

Terminology—The Low Power Mode (Lopomo)

In the electromechanical era, appliances had two operating modes, "on" (or "active") and "off." With the advent of electronics, a third mode appeared between "active" and "off." This is often called "standby" but has many other names depending on the device (or even the manufacturer of the device). An increasing number of devices have additional modes—such as "sleep" and "deep sleep"—between standby and active. Future devices are likely to have many different operational modes between "unplugged" and "active," each with a different level of electricity use and functionality. Figure 1 depicts operational modes and power levels.

This project focuses on the modes between unplugged and active, which we call the "low power modes." To simplify writing and awkward word constructions, we call the low power mode the "lopomo."[2]

It is also important to distinguish between *operational* modes (such as on, sleep, and off) and *power* levels, such as the definitions of standby recently adopted by the Department of Energy (DOE) and the International Electrotechnical Commission (IEC). The DOE and IEC definitions of standby refer simply to the device's lowest power level while connected to the mains, irrespective of functionality.

[1] Additional information is available at http://standby.lbl.gov/CEC_Workshop/
[2] One lopomo, two lopomos.

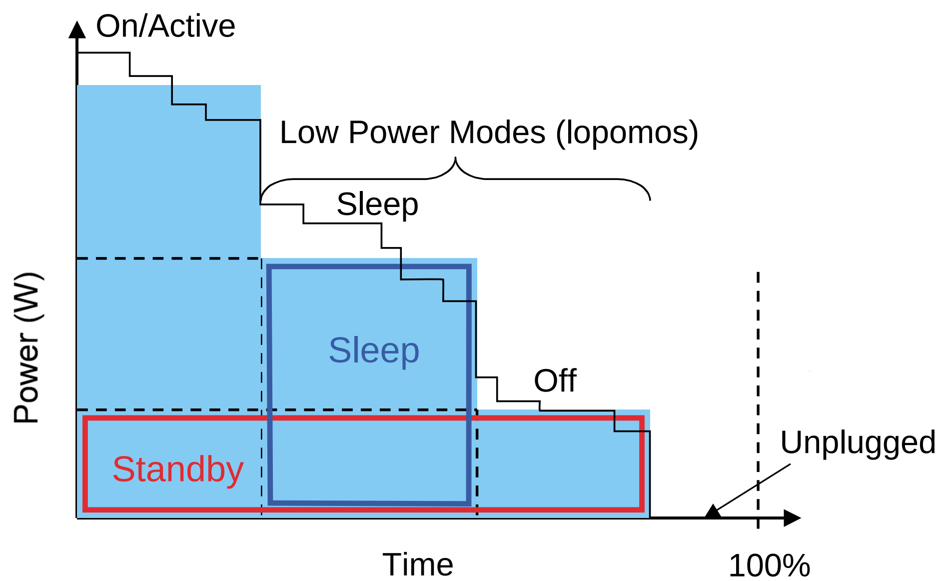

Figure 1. A graphical depiction of the low power modes (lopomos). Most products still have only one or two lopomos, that is a "sleep" mode and an "off" mode.

Review of Literature Related to Low Power Modes

Energy Test Procedures

Consistent definitions and test procedures are essential for reliable and comparable measurements. Unfortunately, responsibility for definitions and test procedures of lopomos are spread among many international groups, with no overall organization or coordination. Many actually conflict with each other, either in definition or procedures. ENERGY STAR established ad-hoc product-specific definitions for most of the products that it covers but even these tests are inconsistent in both large and small aspects.

A technical committee of the IEC (TC 59 WG 9)[3] issued a draft definition and test procedure for standby power in July 2002. The committee's responsibility is white goods, but the test procedure was designed to apply to virtually all electric devices that can be plugged in. No similar, generally applicable test procedure exists for the other low power modes.

Field Measurements

Virtually all measurements to date have been conducted on standby power use in homes. Over one thousand homes around the world have been measured, including some in

[3] The Committee Draft is available at the workshop website, http://standby.lbl.gov/CEC_Workshop/

Europe, Japan, Australia, and China. Only one formal study in the United States has been conducted—10 homes in California—so we have a poor understanding of both the California and U.S. standby situation. Less information is available for other low power modes. Worldwide, residential standby power measurements range from about 30 to 125 W per home, as shown in Figure 2.

Data are even scarcer for the commercial sector. For one class of devices—office equipment—we have rough estimates of energy use, but for the rest we know almost nothing. No commercial buildings have been monitored, so we have essentially no idea how large low-power mode energy consumption is, let alone a comprehensive list of devices with lopomos.

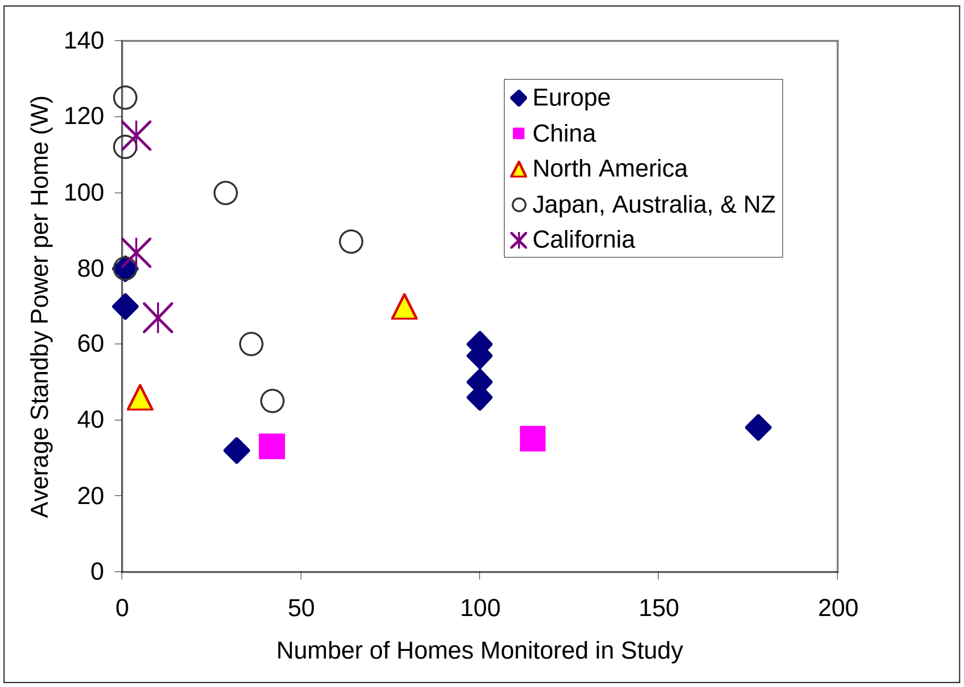

Figure 2. Field measurements of residential standby power use in different countries. Less than 15 homes have been measured in California.

With the available information, we cannot even determine if standby or total lopomo energy use is increasing or declining. ENERGY STAR programs may be lowering standby in common consumer electronics but the rapid appearance of new, digital appliances and the dramatic increase in the number of appliances with standby may be offsetting those gains. Some of the key growth areas for residential standby include set-top boxes, white goods, and home networks. Another problem is "hard-wired" standby caused by smoke detectors, security systems, GFCIs, and HVAC control systems. A unique problem is digital converter boxes for TVs, which may be required for as many as 200 million TVs in the United States—over 20 million in California alone—in the next 5 years, each drawing as much as 20 W.

Energy Use of Low Power Modes in California

There is not enough information to estimate confidently energy consumption of low power modes. Based on the existing data, a "best guess" of residential standby is 70 W per home, which is about 600 kWh/year (more than most new refrigerators), or about 10% of California residential electricity use. The more modest additional energy use of sleep modes must still be added to this number, so 70 W represents a conservative estimate. This corresponds to a California-wide load of about 900 MW (8,000 GWh/year).

There is insufficient information to project lopomo energy use confidently; however, anecdotal evidence suggests that it will rise—probably significantly. The rapid introduction of set-top boxes and other high growth appliances is likely to cause observable increases in statewide electrical demand. New homes are likely to have much higher standby electricity consumption because of a greater number of these hard-wired components and a greater number of electronic products overall.

Data for the commercial sector are even sketchier. Based on very rough assumptions office equipment alone may be responsible for 1,100 GWh/year. The energy use of other products with lopomo energy use, from emergency lighting and exit lights to communications equipment, still need to be included (but no data are available). There is some reason to believe that the energy use of equipment in their low power modes is the fastest growing component of California electricity use.

Energy Efficiency Programs

Voluntary and mandatory programs dealing with low power modes exist in North America, Europe, Japan, Australia, China, and a few other countries. Most of the voluntary programs, such as ENERGY STAR, target the standby mode for consumer electronics and the sleep mode for office equipment. In contrast, the *mandatory* efficiency programs, such as efficiency standards for white goods in the U.S., Europe, Australia and Japan, generally target active modes and ignore the lopomos.

ENERGY STAR operates the world's largest program for consumer electronics and office equipment. ENERGY STAR specifications are arguably the *de facto* world standard for these products.

Research Strategies

There is only limited technical research focused solely on improving the efficiency of lopmos. The wide diversity of products partly explains the lack of specific research on the topic. Nevertheless, research that will impact lopomos is underway. Technologies borrowed from other situations can often be constructively applied to lopomos (such as battery-powered devices, where power consumption is critical). Some corporate research directed to other goals has also led to low-power solutions. For example, the need to reduce heat and weight of power supplies has resulted in greatly improved efficiencies for some products. Manufacturers have successfully cut irritating fan noise by switching off the fan altogether while in a lopomo. This could only be accomplished by reducing component heat generation while the device is in standby or sleep modes.

There are three principal research strategies to reducing the lopomo energy consumption:

- Improve the efficiency of the components
- Improve software to help equipment operation better match functional needs
- Improve (or modify) technologies outside the device and change user behavior

An example of *component improvement* is increasing the efficiency of power supplies in their no-load and part-load performance. Other examples include de-energizing components when not needed and designing ultra-low power circuits.

Software improvements help the device better match operational components with functional needs. These improvements enable the device to shift operating time from active to sleep and from sleep to off. These changes may actually increase energy use while in the low power modes (by shifting operating time from active) but result in lower overall energy use.

External changes can also reduce energy use in low power modes. Important examples are the communications protocols between service providers (such as cable TV providers) and set-top boxes or between a server in a home network and the appliances on the network. In both cases, the protocols need to be designed to enable devices to enter the lowest possible operational state. This requires coordination between the service providers and the box manufacturers. Other external changes include construction of a low-power DC supply network in buildings (to eliminate the need for separate power supplies) and improved user interfaces that make low power modes easier for consumers to identify and use. Research is also needed on consumer behaviors, as well as effective interfaces between consumers and these products.

Recommendations for Research

The following recommendations are based on the input gathered in the August 26, 2002 Workshop, through discussions with other knowledgeable persons in the field who were unable to attend the workshop, and our own judgment. A summary of the Workshop discussions and background information is in the Appendix.

First, the Workshop participants—over half were from industry—strongly endorsed the need for research into the general topic of low power modes. Many saw how this problem would impact their own businesses and felt that early action was advisable. The participants were also comfortable with California funding the research, either alone or in collaboration with the federal government.

Scope of Recommendations

Many of the recommendations that we received from others dealt with overall directions for research or with specific projects. We have used these recommendations to create, first, a framework, and then specific actions as examples. Some parts of the framework already have many specific projects listed (thanks to the Workshop input and our own recommendations) while others remain little more than general research direction.

Major Research Directions

We identified six major directions for research in the area of low power modes:

1. Understand how much energy is actually consumed in the lopomos

2. Develop energy test procedures for lopomos and protocols to measure their contribution to whole-building electricity use
3. Understand human behavior and preferences as they relate to lopomos
4. Investigate feasible technologies offering energy savings opportunities and their economic costs and savings
5. Engage in long-term research to increase the efficiency of lopomos
6. Engage in short-term research to address anticipated critical problems related to lopomos

We discuss each of these broad research areas below.

Research Area No. 1: ***How much energy is actually consumed in the low power modes?***

The Workshop participants were struck by the absence of measurements of lopomo energy use in U.S. buildings, especially compared to the data available from other countries. There was nearly unanimous agreement that better understanding the dimensions of lopomo energy use should be a key research goal. Furthermore, this understanding was necessary before California can undertake comprehensive actions to deal with it. Research is needed to answer such questions as:

- How large is lopomo energy use and how is it distributed across the residential, commercial, industrial, and other sectors?
- Is lopomo energy use growing?
- Are certain products or components responsible for a large part of lopomo energy use?

The answers to these questions will help the Commission and other research agencies select the areas deserving further research or programs. The general approach will involve three steps:

1. Assemble lists of product types with lopomos
2. Measure lopomos of products in situ and in the laboratory, including the fraction of time in each mode and other key information
3. Periodically measure lopomos of new products

Steps 2 & 3 can occur in parallel. Step 2 should involve measuring the electricity use of the whole building (in addition to the contribution of each lopomo product) so that the fraction of electricity devoted to lopomos can be determined and no devices are over-looked.

The residential sector is better understood than other sectors. Most of the products with lopomos have already been identified (though new products are introduced every day). Step one is essentially compete, so work could begin immediately on the measurement phase. Less is known about the commercial sector, where a list of products with lopomos does not even exist.

Some of the specific projects that would fall inside this general category are:

- Gather lopomo energy data in a representative sample of residential buildings by means of large-scale measurement campaigns
- Survey and compile lists of products with lopomo energy use in residential, commercial, and industrial buildings
- Gather lopomo energy data in a representative sample of commercial buildings by means of large-scale measurement campaigns
- Measure the hard-wired lopomo energy use in new, unoccupied homes (and possibly commercial buildings)

Research Area No. 2: *Develop definitions and energy test procedures for low power modes and protocols to measure their contribution to whole-building electricity use*

Standby power use is now fairly well defined and an internationally recognized test procedure is nearly complete. For some ENERGY STAR products, the sleep mode is defined and a test procedure exists. Beyond that, however, there are few similar definitions and test procedures for the lopomos.

International standards organizations (IEC, ISO, etc.) have begun to address this omission, but the pace has been slow and uncoordinated. In fact, some of the groups appear to be heading in divergent, contradictory directions. Consistent definitions and test procedures are an essential precursor to monitoring projects. California can have a major influence on the direction and speed of these standards committees by first investigating the technical options and then participating in the deliberations.

The definitions and test procedures determine how to test the lopomos for a single device. A protocol for measuring the lopomos of all the products inside a building must then be used to collect the data for representative samples (discussed earlier). Again, California can lead by developing procedures and field-testing them.

Research Area No. 3: *Understand human behavior and preferences as they relate to low power modes*

Small differences in operational settings (such as enabling power management features) can easily lead to ten-fold differences in annual energy consumption of many electronic products. For this reason, the human dimensions must be carefully included in all lopomo research. Three areas deserve special attention:

- Can additional consumer education change the way consumers operate a device?
- Can improved product design (e.g., “user interface”) encourage users to exploit the lopomos?
- How much do consumers value the lopomos? For example, in what cases would a hard “off” switch be tolerated? Desirable?

The impact of consumer education and training should not be underestimated. Media campaigns in Japan, Germany, and, to a lesser extent California during the electricity crisis, probably caused many users to more frequently enable the lopomos (or simply unplug devices).

Any program aimed at educating and mobilizing people to use products more efficiently will be more successful if the energy-related controls in these products present a logical, clear, and consistent appearance. Thus, the research necessary to develop and promote design guidelines for controls related to power management is likely to pay off handsomely. The Commission has already initiated research in this area and it appears to be headed towards a successful outcome.

Research Area No. 4: ***Investigate energy savings opportunities and economic feasibilities of technologies to reduce energy use of equipment while in low power modes***

Before California adopts programs to address the lopomo energy use, it needs to better understand the overall technical potential energy savings. From this information, it can determine which programs will save the greatest amount of energy for the lowest total cost. In the course of this research, the following questions will be addressed:

- Which products or components use the most lopomo energy?
- What are the technical options to reduce lopomo energy use and how much will they save?
- How much do those technologies cost?

The results of this research are often depicted as "technology-cost curves" for single devices or "supply curves of conserved energy" for an entire end use category. Developing these curves for lopomo energy use is unusually difficult because so little data exist on energy use, stocks, and patterns of usage. Furthermore, some devices are penetrating the market very rapidly, so energy savings are sensitive to sales rates.

Some products and components are so clearly important that they deserve immediate attention. Set-top boxes and digital converter boxes are good examples of products deserving immediate investigation. Power supplies and battery charging systems are good examples of components that deserve immediate investigation.

Research Area No. 5: ***Engage in long-term research to increase the efficiency of low power modes***

Most efficiency improvements in the lopomos result in savings of only a few watts per product. But the potential savings are large because the improvements apply to so many products and because the products operate in the lopomos so many hours each year. Some savings will also occur when better designed lopomos allow a product to shift time from an active mode to the lopomos.

There are three principal research strategies to reducing the energy consumed in the lopomos:

- Improve the efficiency of the components
- Improve software to help equipment operation better match functional needs
- Improve external aspects to facilitate energy savings

Several components appear ripe for additional efficiency improvements. Power supplies deserve the greatest attention because they exist in all of the products. In many cases, efficiency improvements to power supplies will also save power while the products are in active mode.

Rechargeable products represent an increasing fraction of products with lopomos. Batteries, and the circuitry to charge them, draw upon increasingly sophisticated technologies. Improving the efficiency and overall performance of battery-charger system will yield both energy savings and environmental benefits (by increasing battery longevity). Long-term research could lead to a "California battery" system, with performance characteristics tailored to maximize energy efficiency and minimize disposal costs. Alternatively, adding a battery to a device may allow better power management or reducing standby use to zero.

Manufacturers are striving to add increasing functionality to products while in the lopomos. More efficient circuitry could provide both increased functionality and energy efficiency. This should be another research area. The California-supported CITRIS[4] program is an example: CITRIS researchers developed circuitry with power requirements 1/100 of current levels. Stray air currents, ambient light, and local temperature differences may be able to supply enough power to operate these circuits.

Many California companies, universities, and research institutions are already tangentially involved in these topics and, through collaboration, will be better positioned to market the fruits of the research profitably.

Research Area No. 6: ***Engage in short-term research to address anticipated critical problems related to low power modes***

Short-term research can provide valuable support to program development. Some of the results can be used to as inputs to the technology cost curves and other policy tools. Short-term research can also demonstrate proof of a concept to justify additional research or the technical feasibility of a mandatory standard.

Television set-top and digital converter boxes are obvious targets for short-term research. This research could investigate technologies to reduce power consumption through improved components and communications protocols. By demonstrating that boxes with lower power use are technically feasible (and economic), the Commission can develop programs to address the anticipated flood of these boxes.

Hard-wired standby in new homes was already identified as an important measurement target. Another example of short-term research would be the development of prototype smoke detectors, built-in LED lighting systems, and other products that would offer the same functionality at lower power levels.

Overall Conclusions and Recommendations

Even with the limited information available, the electricity consumed by devices while in lopomos already represents a significant fraction of California’s total consumption. In California’s homes, standby power consumption alone probably accounts for nearly 10% of total residential electricity use. There is also evidence that lopomo energy use will rise sharply. These trends suggest that California is justified in undertaking a range of programs to reduce lopomo energy use.

We have outlined a framework for research, plus many targeted projects. The research covers a broad spectrum of activities, from field measurements to understanding consumer behavior to exploration of entirely new technologies. Some of these projects—such as development of energy test procedures—need to begin almost immediately. Other aspects—such as investigations of new technologies—can wait. But, together, this research agenda will ensure that programs to reduce the energy use of low power modes will be effective for both the short and long term.

[4] Center for Information Technology Research

Appendixes

All of the documents are available in electronic form at the Workshop website: http://standby.lbl.gov/CEC_Workshop/

- Measurements of Standby Power—A Survey of the International Literature
- California Energy Use and Savings Potential
- Survey of Programs Related to Low Power Modes
- Reducing Energy Use in Low Power Modes: Research Directions
- Meeting summary